

FIRST EXPERIENCE IN ATRIAL ACTIVATION IMAGING FROM CLINICAL ELECTROCARDIOGRAPHIC MAPPING DATA

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Abstract-Activation time (AT) imaging from electrocardiographic (ECG) mapping data has become feasible under clinical conditions. First clinical results have recently been described on the validation of the sinus rhythm in the human ventricle. In this pilot study the AT imaging approach is applied for the first time to data of the human atrium. Because of the complex anatomy and of the small atrial signal electrical source imaging is a huge challenge. The reconstructed AT pattern for the sinus rhythm on the endo- and epicardium was compared with the CARTO™ map obtained for the right atrium in a 21 year-old male patient. The geometrical error for the target chamber was found to be 4.8mm. The spatial dislocation for the first endocardial breakthrough (sinus node activation) was determined with 5mm.

Keywords - Activation time imaging, human atrium, geometrical modeling, cardiac electrophysiology, inverse problem

I. INTRODUCTION

Combined magnetic resonance imaging (MRI) of the torso anatomy and electrocardiographic (ECG) mapping enables noninvasive imaging of the primary electrical sources in the human heart [1-7]. The primary source in the cardiac muscle is the spatio-temporal transmembrane potential ϕ_m distribution [5]. For depolarization, the assumption of electrical isotropy in the myocardium proves valid. Because of the unknown individual fiber orientation this hypothesis is applied in this study, too. Herewith the forward and inverse formulation can be reduced to a two-dimensional field and scalar potential problem. In general, the boundary element method is applied for this kind of problem. In the inverse problem parameters describing features of ϕ_m or the epicardial potential are estimated [3, 6, 9]. The epicardial potential as well as the potential on all other conductivity interfaces are related to ϕ_m by an integral equation [5]. The most established inverse formulations are imaging the AT map on the entire surface of the heart and the epicardial potential pattern.

In clinical electrocardiology arrhythmias within the human atrium and their therapeutic treatment play a dominant role [8]. Currently, the localization of the origin of arrhythmias is achieved by traditional catheter techniques and by recently introduced catheter mapping techniques (e.g., CARTO™ [2]). These methods have limitations, e.g. they do not allow acquiring a single beat activation map. The single beat AT imaging approach would provide this information fully noninvasive. From a clinical point of view this might have several advantages.

The AT imaging methods permit the reconstruction of single focal, multiple focal and more distributed activation patterns. Furthermore, these methods can distinguish between areas with early and late activation. Potential clinical applications of the ECG inverse problem are noninvasive imaging of atrial and ventricular ectopic as well as pre-excited activation.

In this pilot study we investigated the application of the AT imaging method to a clinical data set of the human atrium. The geometrical model and the reconstructed AT map of the right atrial activation was compared with the electro-anatomical CARTO™ map.

II. METHODOLOGY

A. Study protocol

One male subject, 21Y with structural normal heart and WPW syndrome underwent radio frequency (RF) ablation of the accessory pathway. Before treatment in the catheter laboratory individual anatomical data was obtained by magnetic resonance imaging (MRI) using a Magnetom-Vision-Plus™ 1.5T scanner. Atrial and ventricular geometry was recorded in CINE-mode during breath-hold (expiration, 21×7 oblique short axis scans, 4 and 6mm spacing). The lungs and the torso shape were recorded in T1-FLASH-mode during flat breath-hold (expiration, 40 axial scans, 10mm spacing). 12 markers (vitamin E capsules, 7 anatomical landmarks on the anterior and lateral chest wall, 5 electrode positions on the patient's back) were used to couple all data acquired geometrically to the MRI frame. From this data set a boundary element volume conductor model was built up.

The patient was moved to the catheter laboratory and ECG mapping data was recorded during the diagnostic catheter study. Electrocardiographic mapping data was collected in 62-channels by the Mark-8 system. A Wilson-terminal defined the reference potential. The sampling rate was 2048 Hz. Signals were bandpass filtered with a lower and upper edge frequency of 0.3 Hz and 400 Hz, respectively. The AC-resolution of the system is 500 nV/bit (16 bit per channel).

Radiotransparent carbon electrodes were used in order to allow simultaneous X-ray examination. The position of 52 electrodes on the anterior and lateral chest wall was digitized by the Fastract® system. Additionally, the positions of the 7 anterior and lateral landmarks were digitized in order to allow coordinate transformation to the MRI frame. The locations of the 5 upper posterior electrodes were identical with the position of the 5 posterior MRI markers.

The ECG raw data was pre-processed by baseline correction, but no additional filtering was applied. The transfer matrix was calculated applying the boundary element method with linear triangular elements. In the inverse problem the AT map was determined from single beat ECG mapping data applying a nonlinear optimization routine for the estimation of the onset of the transmembrane potential at each node of the surface model of the entire atrium. More detailed information on the surface transmembrane potential inverse approach can be found in [5-7].

Report Documentation Page		
Report Date 25 Oct 2001	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle First Experience in Atrial Activation Imaging From Clinical Electrocardiographic Mapping Data		Contract Number
		Grant Number
		Program Element Number
Author(s)		Project Number
		Task Number
		Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Biomedical Engineering Graz University of Technology Graz, Austria		Performing Organization Report Number
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500		Sponsor/Monitor's Acronym(s)
		Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited		
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 4		

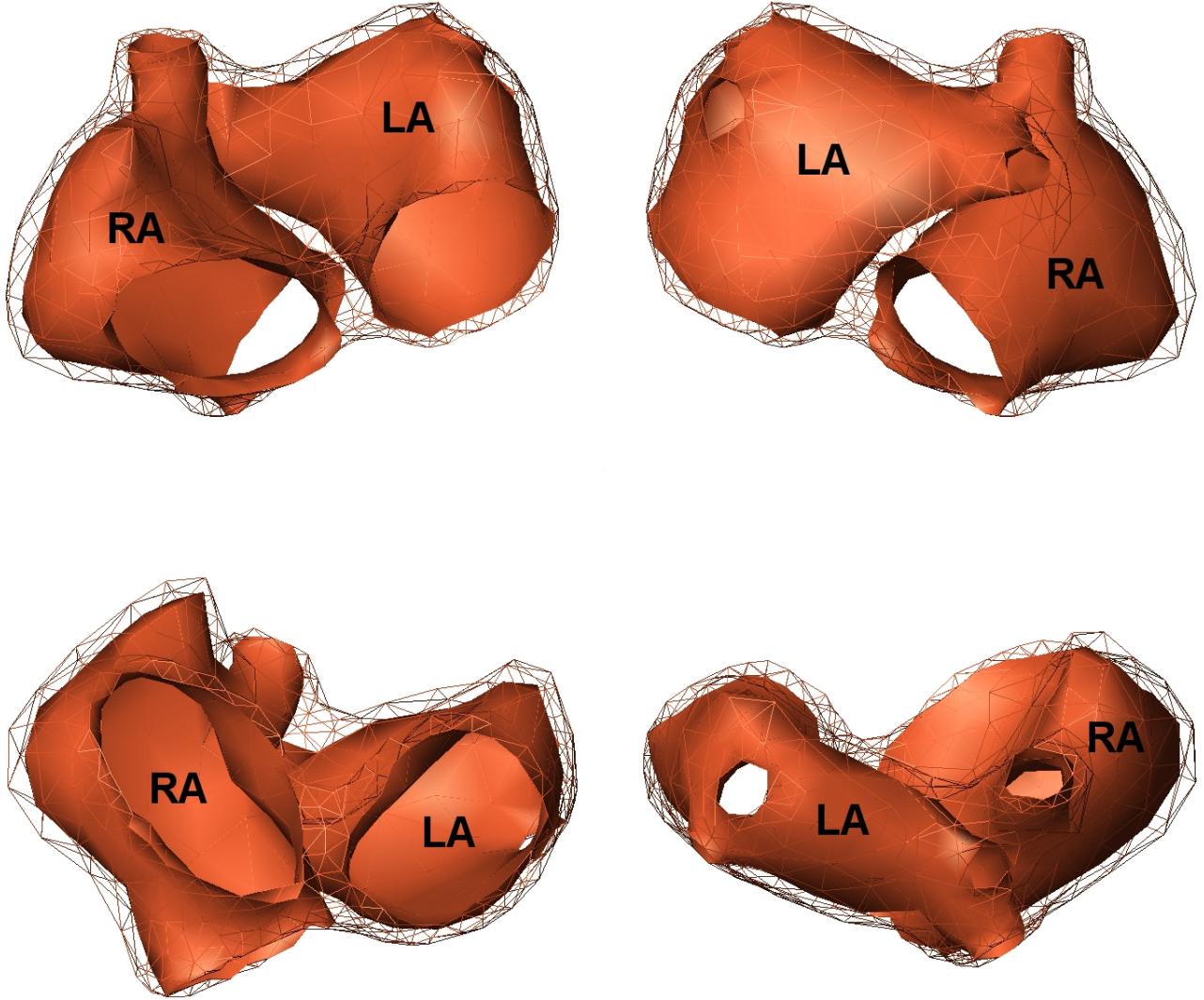


Fig. 1: ECG-gated boundary element model of the atrium (RA, LA ... right and left atrium) of the male subject from an anterior (left upper panel), posterior (right upper panel), caudal (left lower panel) and cranial (right lower panel) view at 600ms trigger delay after the R-peak. The model consists of 1490 elements with 735 nodal points. The model was built up from short-axis scans with 4mm slice thickness. The epicardium was modeled assuming an uniform wall thickness of 4mm. The pulmonary veins, the Vena cava inferior and superior as well as the tricuspidal and mitral annulus were considered.

B. Geometrical modeling of the human atrium

Because of the complex anatomy of the human atrium there are several aspects in the evaluation of a “good” surface model. First, specific care has to be taken on the MRI protocol in obtaining scans with a high gray-value contrast. The model shown in Fig. 1 was obtained from short-axis scans with 4mm slice thickness in a CINE-mode during breath-hold. For the atrial end-diastolic phase the trigger delay was 600ms after the R-peak. The model consists of 1490 elements with 735 nodal points. The epicardium was modeled assuming a uniform wall thickness of 4mm for the left and right atrial free wall. Specific attention has to be paid to the identification of the pulmonary veins, the Vena cava inferior and superior as well as to the tricuspidal and mitral annulus. The modeling of these structures is important for this kind of inverse formulation, in which the considered surface area gives signal space in the forward problem when once electrically

activated. Because of the sophisticated curvature and of the narrowness of the individual endo- and epicardial boundary element surfaces the proper meshing is of utmost importance in order to obtain a high-quality transfer matrix relating the transmembrane potential on this surface to the ECG mapping data.

III. RESULTS

Activation time imaging was performed for the ventricle (sinus rhythm, WPW) and for the atrium (sinus rhythm). Fig. 2 depicts the map for the atrial sinus rhythm AT pattern. The activation time τ is shown in ms beginning with the onset of the P wave. The earliest activation was reconstructed close to the Vena cava superior (VCS) reflecting the sinus node area. The first breakthrough in the left atrium (LA) was observed anterior in between the septal and the left atrial appendage

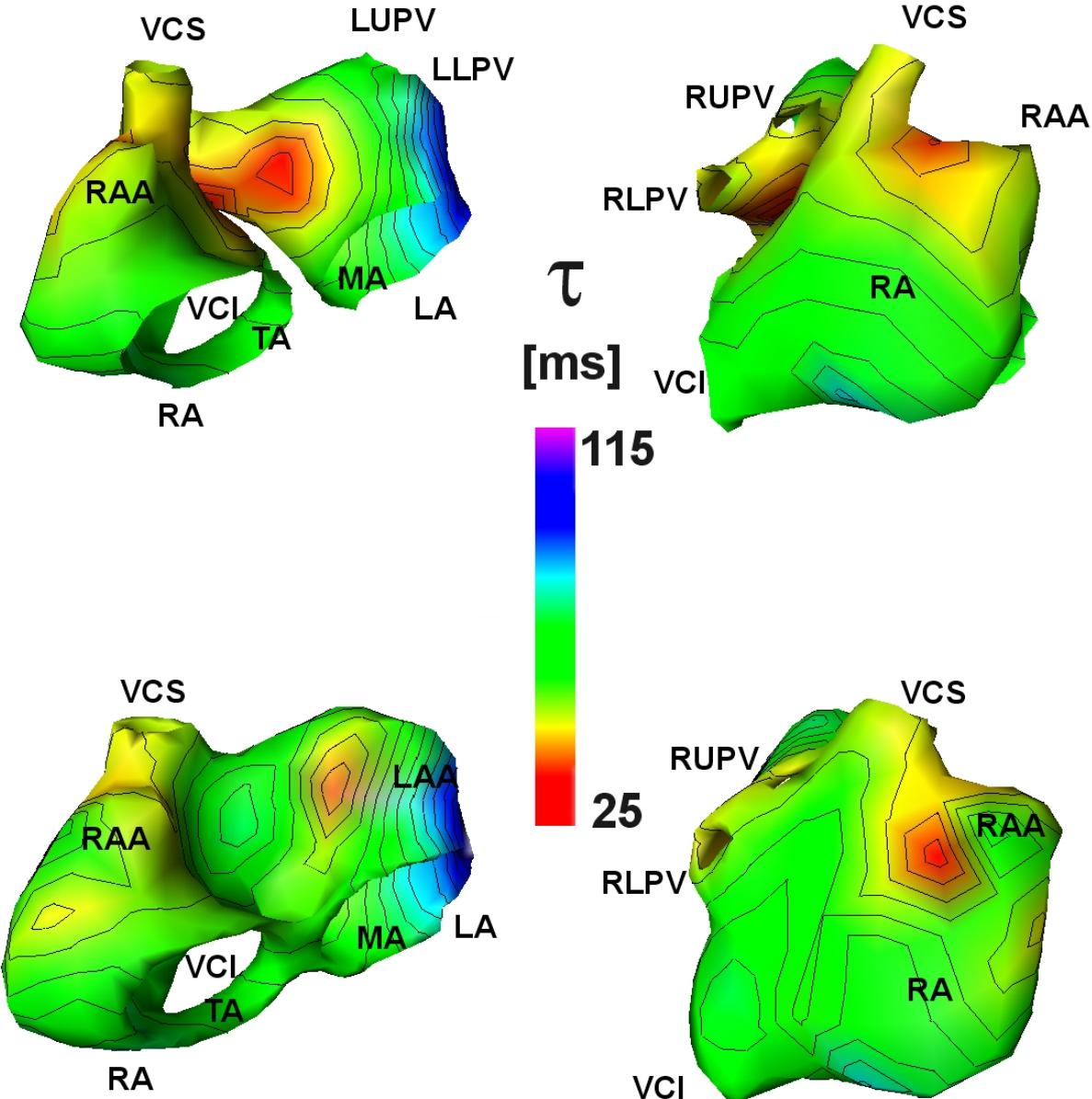


Fig. 2: Activation time map in the atrium of the male subject from an anterior (left panels) and from a right lateral (right panels) view. The upper and the lower panels show the endocardial and epicardial pattern, respectively (MA, TA ... mitral and tricuspidal annulus; RAA, LAA ... right and left atrial appendage; RUPV, RLPV ... right upper and right lower pulmonary vein; LUPV, LLPV ... left upper and left lower pulmonary vein; VCS, VCI ... Vena cava superior and Vena cava inferior). The activation time τ is shown in ms beginning with the onset of the P wave. The earliest activation was reconstructed close the VCS reflecting the sinus node area. The earliest breakthrough in LA was observed anterior in between the septal and the LAA area.

(LAA) area. From the right atrium (RA, target chamber) the CARTO™ map was acquired including 43 points, non-uniformly spaced on the endocardium of RA. The geometrical error for the target chamber was found to be 4.8mm. The spatial dislocation for the first endocardial breakthrough (sinus node activation) was determined in the order of magnitude of 5mm. The sinus rhythm pattern for the left atrium (LA) is in accordance with the clinical knowledge about LA activation. In particular, the first breakthrough was determined on the anterior wall, associated with the conduction from RA to LA through the Bachman bundle. The reconstructed ventricular sinus rhythm and WPW pattern were

found to be in good agreement with the clinical findings (see [7] in these proceedings). The WPW bundle was identified close to the right ventricular outflow tract (RVOT) where RF ablation occurred.

IV. DISCUSSION

To the authors best knowledge this is the first study reporting on AT imaging within the human atrium. In this pilot study only one patient and a sinus rhythm sequence was considered. In principle, we have shown that the specific AT inverse formulation is capable of imaging the atrial activation sequence. The inverse solution showed sufficiently numerical

stability. In the process of modeling and inverse computation we recognized that the consideration of an accurate model of the subject's atrium is important. ECG gating and proper coupling of the model to the ECG mapping data do have great impact on the numerical stability.

The localization accuracy of 5mm has to be considered as a "qualitative" measure. First, because of the problems in coupling the CARTO™ map with the geometrical surface model and due to the given accuracy of the CARTO™ map itself. Second, because the reconstructed single beat AT image is compared with an electroanatomical AT image acquired in an ECG-gated mode during a sequence of beats (e.g., in this subject by considering 43 beats). Further, in this pilot study the CARTO™ map consisted of 43 sampling points only. Additionally, these points were not spaced uniformly. These problems let one realize that a quantitative comparison becomes quite though and is sometimes even impossible from an engineering and mathematical point of view. Therefore, a qualitative comparison of the two AT maps is of great value, too.

Current research focuses on clinical validation of sinus and catheter paced atrial and ventricular rhythms. Further studies intend to show the reproducibility of source imaging within the human atrium and ventricle under clinical conditions.

ACKNOWLEDGMENT

This study was supported by the Austrian Science Fund (FWF) under grant START Y144-INF. We would like to thank Maria Abou-Harb for her technical assistance in the catheter laboratory.

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